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Application for Patent

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...ention the title of which is

(בעברית)
(Hebrew)

התקן תאורה לסורקים אופטיים

(באנגלית)
(English)

ILLUMINATION DEVICE FOR AN OPTICAL SCANNER

מבקש בזאת כי ינתן לי עליה פטנט
...for a patent to be granted to me in respect thereof.

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היום 2 בחודש II שנת 1987
This 2 of II of the year 1987

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The present invention relates to an illumination device for an optical scanner of the type used in automated inspection, and more particularly, to an efficient device which delivers intense, multi-directional light energy to the target area.

Automated optical inspection machines usually incorporate some type of an electrooptic scanner. The scanning apparatus generally includes a light source which delivers light energy to the surface under inspection. In some types of scanners, the surface is imaged onto a sensor, and either the sensor or the surface or both are mounted on translating mechanisms, which allow the entire surface to be scanned by the sensor.

The primary demand on the illumination apparatus is to provide intense light level at that part of the surface which is sensed by the sensor, such that the full dynamic range of the sensor can be obtained at the highest possible scan rate.

Another primary requirement concerning the illumination apparatus is that it be energy- and light-efficient. Energy efficiency contributes to a reduction of power and heat dissipation requirements, whereas light efficiency, in addition to enhancing energy efficiency, also minimizes the effects of flare and stray light on imaging system and sensor performance.

Another aspect of the illumination that is often required in electrooptic scanners is controlled angular spread. To cope with workpieces that are not perfectly flat, but rather exhibit some degree

of surface relief, such as grooves or scratches, a broad angular spread is necessary to prevent shadowing. In objects that reflect light diffusely, such shadowing may be the result of occlusion of an area by a raised part nearby. However, this problem is more typical of specular surfaces, where shadowing may be the result of no illuminating light rays satisfying the condition for reflection in the direction of the sensor. A broad and continuous range of illumination angles can provide an even illumination in such cases. Illumination should not be overly broad, however, or a loss of contrast between the specular and diffusely reflecting areas may result.

At the other extreme, some inspection tasks may benefit from the use of narrow, strictly bright-field illumination. In general, it is highly desirable to have an illumination apparatus in which the balance between the specular, or bright-field illumination on the one hand, and the diffuse, or dark-field illumination on the other hand, can be varied to suit the application.

A widely used sensor type for electrooptic scanners is the line sensor, usually of the CCD or photodiode array technology. With such a sensor, the workpiece area that is sensed at any given time is a relatively narrow line, having a typical aspect ratio of 1:1000 or even 1:2000. An efficient illumination system should therefore confine the light to an elongate area straddling the sensed line.

Some systems use elongate quartz-halogen lamps along with slab-like light guides. These allow the lamps to be remotely mounted to avoid workpiece heating problems. The slab exit aperture subtends a

fixed angle of about 30^{o}-40^{o} at the workpiece and is ground to diffuse the light. This arrangement is only moderately efficient, because multi-directional illumination is gained at the expense of spreading the light over a relatively wide area. This arrangement also lacks flexibility, since the angular spread of the illumination is fixed.

A more flexible type of illumination apparatus for line scanners employs optical fiber bundles. The input end normally has a circular cross section and accepts light from quartz-halogen lamps with a collimating reflector. The output end is shaped into a linear slab having a typical aspect ratio of between 1:80 to 1:400. The long and narrow ends of several such bundles may be combined to illuminate the working surface at different angles. This arrangement is more flexible than the one described before, since the operator has the option of choosing between various combinations of active bundles. However, this type of illumination does not satisfy the requirement for continuous angular spread, since the working surface is only illuminated from few, discrete directions. Power and light efficiency is basically similar for both techniques.

Some electrooptic scanners are known to employ elongate fluorescent lamps, either in close proximity to the working surface, or in combination with light guides as described above. Fluorescent lamps inherently have a better power efficiency than quartz-halogen lamps, and they can also provide a smooth, broad and continuous angular spread when used at close proximity. Their radiance, however, is inferior to that of quartz-halogen lamps, which gives rise to relatively low light levels that are inadequate in many cases.

In conclusion, it is noted that all the illumination techniques described above share the same fundamental limitation of having to compromise light efficiency to gain a broad and uniform angular spread. In addition, a true bright-field illumination is usually achieved by orienting the sensor optical axis at a finite angle with respect to the normal to the working surface, thereby having part of the illumination satisfy the condition for specular reflection. Increasing the angular coverage of the illumination would therefore involve mounting the camera at a still larger inclination. This has the adverse effect of introducing distortions to three-dimensional features of the workpiece.

An illumination apparatus is known to exist which uses a beam-combiner to introduce bright-field illumination along the vertical optical axis of the camera. The dark-field component of that system, however, is highly discrete, and light efficiency is relatively poor.

It is one of the objects of the present invention to overcome the drawbacks and deficiencies of prior-art illumination devices for optical scanners, and to provide an illumination device that produces a broad, continuous and nearly uniform angular coverage, that improves luminance levels at the workpiece area and makes more efficient use of available light energy, that is flexible in operation and permits the user to choose bright-field or dark-field illumination or any weighted combination of both, that allows a strictly vertical optical axis of the camera to minimize distortion of relief patterns and minimizes degradation of the optical performance of the camera associated with the

use of a beam combiner, and that allows the camera lens to approach the working surface to within the shortest possible working distance.

This the invention achieves by providing an illuminating device for optical scanners, comprising one or more light sources for illuminating a line-like portion of a workpiece to be scanned, and a beam concentrator for each of said light sources, wherein said beam concentrators are so located relative to said light sources on the one hand and to said line-like portion to be scanned on the other, as to produce, on said line-like portion, an elongate, relatively narrow image of said light sources, said image substantially covering said line-like portion to be scanned, whereby said illuminating device is usable for bright-field illumination or dark-field illumination, or a weighted combination thereof.

While the drawings and the description relate to an embodiment in which the light sources are effectively represented by the output ends of light guides, it should be understood that the invention as claimed does not reside in the use of light guides, in spite of their above-cited per se known advantages, and that an embodiment is envisaged that does not make use of the effective light sources represented by the output ends of light guides, but employs light sources directly, without the intermediary as constituted by optical fibers.

It should also be noted that since the output end of each light guide does in fact constitute the effective light source, the term "light source" as used in the description is regarded as applicable both to the actual light sources at the input ends of the light guides

and to the equivalent or effective light sources constituted by the output ends of the light guides.

The invention will now be described in connection with certain preferred embodiments with reference to the following illustrative figures so that it may be more fully understood.

With specific reference now to the figures in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

In the drawings:

Fig. 1 is a schematic representation of a preferred embodiment of the illuminating device according to the invention;

Fig. 2 is a perspective view of a fiber-optics light guide as used in the device of Fig. 1, and

Fig. 3 represents the optical scheme of the device according to the invention.

Referring now to the drawings, there is seen in Fig. 1 a schematic representation of a preferred embodiment of the illumination device according to the invention, as configured for combined bright-field and dark-field illumination. Seen is a schematic cross section of the device in a direction perpendicular to the surface line that is sensed by the line-scan camera 2. Point 4 is the intersection of the line about to be scanned with the optical axis of the camera. The illumination device comprises light sources represented by three flat fiber-optic light guides, 6,8,10, available, e.g., from Schott Glass of the Federal Republic of Germany, or Incom of the U.S.A.

A typical example of such a light guide is shown in Fig. 2. The guide is comprised of four distinct fiber bundles A, B, C, D of a substantially circular cross-section at the input end, which, inside the housing 12 fan out, to constitute a narrow, elongate output end 14, having an aspect ratio of up to 1:400. Each bundle may have its own light source (not shown), advantageously in the form of a quartz-halogen lamp provided with a collimating reflector. These light guides have the advantage of providing the high radiance available from such sources, while keeping the heat generated by the lamps away from the workpiece and operator. The light guides are mounted on their respective supports 16, one for each side of the guide. The supports themselves are attached to side plates 18, to which are attached also the other components of the device, as will be shown further below.

The output ends of the light guides constitute an elongate source of light which extend in a direction parallel to the direction of the sensed line on the workpiece surface, namely perpendicular to the

paper of Fig. 1. The longer dimension of above source may vary according to application, and it will typically be slightly longer than the workpiece area to be sensed by the line-scan camera 2.

The light output from guides 6, 8, 10 is collected by trough-like concentrators 20, 22, 24 respectively, produced by the generatrix of either a circular or an elliptical cylinder, and mounted on their respective supports 26, 28, 30. The advantages of using reflecting as against refracting concentrators are several: The reflecting concentrator does not suffer from chromatic aberration, it facilitates apparatus compactness due to the possibility of folding light paths and, last but not least, it is far less expensive to manufacture.

The orientation of the concentrators is such that the above mentioned generatrices are parallel to the line on the workpiece surface to be scanned. The concentrators 20, 22 and 24 are placed at the appropriate distances and orientations so as to form an approximate image of the respective light source on the working surface. The imaging relation here is generalized in the sense that each point of the effective light source is imaged to constitute a line section on the surface, the length of which section is determined by the angular spread of the light in the direction of the normal to the paper in Fig. 1. The imaging process is further approximate in the sense that the above line section image is subject to geometrical aberrations. The imaging process can be made more precise for a sufficiently narrow light source by using concentrators which, according to the above definition, are based on the elliptical, rather than the circular, cylinder.

The lateral concentrators 20, 22 are dimensioned and positioned so as to direct light at the surface with an angular spread covering the range between about 5^{o} to 30^{o} to the optical axis of the camera 2. The lower value is set so that the concentrators do not block the light that is reflected from the sensed area, to be collected by the camera lens, and may vary somewhat in accordance with the maximum useful numerical aperture of the lens. The upper value is chosen so as to form a uniform, non-shadowing illumination of the workpiece relief pattern, and to provide an efficient utilization of the available light energy. This value may also vary according to application.

The light output from the overhead light source or guide 10 is projected onto the working surface after being reflected off a beam combiner 32. The beam combiner is a flat, 2 mm thick glass plate, coated with a thin layer of chrome. Whereas chrome has the advantage of being relatively inexpensive, a higher efficiency (lower losses) may be obtained using dielectric coating. The combiner is mounted inside a frame 34 and is supported by mount 36. The concentrator 24 and beam combiner 32 are dimensioned, placed and oriented so as to form an angular distribution of light at the sensed area that fills the gap between lateral concentrators 20 and 22. This results in a nearly continuous angular coverage as observed from the working surface. The beam combiner is fabricated to have nearly equal transmittance and reflectance to ensure optimum utilization of available light power. The orientation of beam combiner 32 is chosen so as to minimize the detrimental effect of astigmatism on camera lens performance. Like- wise, it is made of glass of minimum thickness, to minimize spherical aberration. The width of the light sources or

guide ends, namely their dimension in the plane of Fig. 1, is also likely to vary according to application. Because of the geometrical aberrations of the cylindrical concentrators, a certain minimum width is required so that a uniform-illumination angular coverage is obtained at the sensed area. Beyond that minimum width, any additional width will only have the effect of increasing the range about the sensed area, both along the optical axis of the camera and perpendicular to it, where both uniform angular coverage and high intensity illumination are obtained. It will, however, have no effect on the illumination level at the sensed area itself. The arrangement illustrated in Fig. 1, therefore, has the advantage of having both wide angular coverage and high light efficiency. The reason is that the cylindrical concentrators project an effective source, as observed from the working surface, having approximately the same radiance as the actual source, but subtending a much wider angle. Furthermore, that angle is independent of source width beyond a certain minimum value, determined by aberrations, as discussed above. In practice, due to the spread in workpiece thickness and finite tolerances of mechanical mounts, a wider effective source is required to form a finite volume in which optimum illumination conditions persist.

The above useful illumination volume may be increased to suit a given application by introducing aberrating plates, such as ground glass of varying granularity, between the light sources or the output apertures of light guides 6,8 and the corresponding concentrators 20, 22. These aberrating plates are designated 38 and 40 and are mounted on their respective supports 42, 44.

The supports 16, 26, 28, 30, 36, 42 and 44 are all located between, and bolted to, two side plates 18 connected to each other by cross bars 46. The side plates are suspended from guiding bars 48, to which they are connected by rods 50 and clamping blocks 52.

The illumination device described so far generates an illuminated area on the working surface that exhibits a non-uniform level along its length. In particular, there is a light fall-off towards the ends of the sensed line due to the finite length of the light sources or guides. This fall-off can be partially compensated for by the installation of planar reflectors 54 attached to the side plates 18. These planar reflectors 54 are mounted flush with the ends of the light sources or guides, 6, 8 and concentrators 20, 22, with the reflecting side facing inward. For effective operation, the reflectors 54 are designed with the bottom edge as close as possible to the working surface.

The optical scheme for the device shown in Fig. 1 which, as already mentioned, combines bright-field and dark-field illumination, is represented in Fig. 3, in which for sake of clarity all mechanical components such as supports, frames, rods, etc. have been eliminated.

With some modifications, the illuminating device as shown in Fig. 1 can also be used for dark-field illumination only. To this end, the beam combiner 32 and the aberration plates 38 and 40 are removed, and light source 10 is inoperative. In such a configuration, light arrives at the working surface from concentrators 20 and 22 only. No illuminating light ray exists that satisfies the law of specular reflection from the nominal working

surface into the sensor. The only light reaching the sensors is that from diffuse or irregular portions of the workpiece, in accordance with the definition of dark-field illumination.

Some important classes of workpieces contain materials that scatter light by a mechanism known as multiple reflections. With such workpieces, the contrast between the multiply reflecting parts and other parts, such as metals, can be enhanced through the use of suitable polarizing filters, which replace the aberrating plates 38 and 40, as well as the beam combiner 32 and produce polarization in the illuminating light beams.

The polarizing filters can be utilized in either of two preferred modes of operation. In the first one, the upper polarizer replacing the beam combiner 32 is polarizing orthogonally with respect to the lower polarizers, replacing the aberration plates 38 and 40, and therefore acts as an analyzer. Its effect is to strongly attenuate light reflected from such reflectors as metals or dielectric materials, that do not alter the direction of polarization of the light. On the other hand, multiply reflecting surfaces cause a depolarization of incident light, and therefore light reflected off these parts is only partially attenuated.

In the second preferred mode of operation, the upper polarizing filter is polarizing in parallel with respect to the other two polarizers in this mode, light reflected off polarization-preserving surfaces is only weakly attenuated, whereas light relected off depolarizing surfaces is attenuated to a higher degree.

Both modes of operation are possible with either linear or circular polarizers.

In either one of these modes, the upper light source or guide is non-operational.

While in the embodiment described, the light guides were of the fiber-optical type, other light guides, for instance, of the solid type, can also be used.

It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrative embodiments and that the present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

IN THE CLAIMS

1. An illuminating device for an optical scanner, comprising:

a) a plurality of light guides representing, at their output ends, elongate, relatively narrow light sources extending in a direction substantially parallel to the direction of a line to be sensed on the surface of a workpiece, and

b) a beam concentrator for each of said light guides, wherein the beam concentrators are constructed and arranged relative to said light sources and to said line to be sensed so as to simultaneously illuminate the entire line with an at least approximate image of the light sources.

2. The illuminating device as claimed in claim 1, wherein said light guides are fiber-optical light guides.

3. The illuminating device as claimed in claim 1, wherein said beam concentrator is of the reflecting type.

4. The illuminating device as claimed in claim 1, wherein said beam concentrators are concave surfaces produced by the generatrix of a cylinder.

5. The illuminating device as claimed in claim 4, wherein said cylinder is a circular cylinder.

6. The illuminating device as claimed in claim 4, wherein said cylinder is an elliptical cylinder.

7. The illuminating device as claimed in claim 1, further comprising aberration plates interposed between at least some of said light guides and their associated beam concentrators.

8. The illuminating device as claimed in claim 1, further comprising at least one planar mirror mounted in a substantially normal orientation to said line to be sensed, near at least one output end of at least some of said light guides to compensate for fall-off of light intensity towards said end.

9. The illuminating device as claimed in claim 1, further comprising polarizing elements interposable in the light path between said light guides and said illuminated line to be sensed.

10. The illuminating device as claimed in claim 1, further comprising at least one polarization element interposable in the light path between said illuminated line to be sensed and a camera.

11. An illumination device for an optical scanner for illuminating a line on the surface of a workpiece, said device comprising:

a) a first elongated light source extending in a direction substantially parallel to the direction of said line; and

b) a first reflective beam concentrator operatively associated with said first source, and being constructed and arranged so as to concentrate the output of said first light source on the entire length of said line.

12. An illumination device according to claim 11 including:

a) a second elongated light source extending in a direction substantially parallel to the direction of said line; and

b) a second reflective beam concentrator operatively associated with said second light source, and being constructed and arranged so as to concentrate the output of said second light source on the entire length of said line such that light from each beam concentrator is superimposed on said line.

13. An illumination device according to claim 12, wherein said first source is positioned on one lateral side of said line, and said second source is positioned on the opposite lateral side of said line, said first and second beam concentrators being spaced apart to define an opening aligned with said line to permit the passage of light reflected from said line through said opening to a camera.

14. An illumination device according to claim 13, wherein said first and second beam concentrators each includes reflective means having a trough-like shape.

15. An illumination device according to claim 14, wherein said trough-like shape is a circular cylinder.

16. An illumination device according to claim 14, wherein said trough-like shape is an elliptical cylinder.

17. An illumination device according to claim 13, further including a planar reflector positioned adjacent each axial end of said line and oriented perpendicular to said line.

18. The device of claim 1, wherein said beam concentrators each direct light from the corresponding light source onto said line, so as to provide a solid angle of uniform

illumination of said line on either side of the optical axis of the scanner.

19. The device of claim 18, wherein the solid angles of uniform illumination provided by said beam concentrators are spaced from one another about said optical axis.

20. The device of claim 19, further comprising a third beam concentrator, a third light source, and a beam combiner, said beam combiner being located on said optical axis, said third beam concentrator and third source being located with respect to said beam combiner such that:

a) said line is simultaneously illuminated with an at least approximate image of said third light source; and

b) a solid angle of uniform illumination is provided by said third beam concentrator, which fills the space between the solid angles of illumination provided by said first and second beam concentrators, and which is centered about said optical axis; and

wherein the level of illumination provided by the third beam concentrator is substantially uniform with respect to the level of illumination provided by the first and second beam concentrators.

21. The illuminating device as claimed in claim 20, wherein said beam combiner is constituted by a semi-transmissive,

i-reflective surface interposed in the light path between said dditional beam concentrator and said line to be sensed.

22. The device of claim 12, wherein said first and second beam concentrators each direct light from the corresponding light source onto said line so as to provide a solid angle of uniform illumination of said line on either side of the optical axis of the scanner.

23. The device of claim 22, wherein the solid angles of uniform illumination provided by said first and second beam concentrators are spaced from one another about said optical axis.

24. The device of claim 23, further comprising a third beam concentrator, a third light source, and a beam combiner, said beam combiner being located on said optical axis, said third beam concentrator and third source being located with respect to said beam combiner such that:

a) said line is simultaneously illuminated with an at least approximate image of said third light source; and

b) a solid angle of uniform illumination is provided by said third beam concentrator, which fills the space between the solid angles of illumination provided by said first and second beam concentrators, and which is centered about said optical axis; and

wherein the level of illumination provided by the third beam concentrator is substantially uniform with respect to the level of illumination provided by the first and second beam concentrators.

25. An illumination device according to claim 23, wherein said combiner is partly reflective and partly transparent.

26. Illumination apparatus for substantial uniform focussed illumination along a narrow linear region comprising:

first and second reflector means elliptically cylindrical segments in shape, each with its long axis substantially parallel to the long axis of the other, and each being spaced-apart from the other along their closest edges to define a path through which the illuminated linear region can be viewed from above through said illumination apparatus;

third and fourth reflector means each being flat and mounted parallel to the other and at opposite ends of each of said first and second reflector means and substantially perpendicular to the long axis of each of said first and second reflector means; and

first and second linear light source means each mounted parallel to a corresponding one of said first and second reflector means to direct light onto substantially the entire surface of the corresponding reflector means with the illuminated

near region at one focus of each of the first and second reflector means.

27. An inspection apparatus as in claim 26, wherein said first and second linear light source means each include fiber optic bundle with exit ends that are narrow in height and substantially as wide as the illuminated linear region and an incoherent light source disposed to illuminate the entrance ends of said first and second fiber optic bundle.

28. Illumination apparatus as in claim 26, wherein said first and second linear light source means each include a light source having a length that is substantially as long as the illuminated linear region is long, and that is parallel to a corresponding one of said first and second reflector means with each of the light source means mounted so that it is at the first focus of the corresponding reflector means and the illuminated linear region is at the second focus of each of the first and second reflector means.

29. Illumination apparatus as in claim 28, further includes:

fifth reflector means elliptically cylindrical segments in shape with its long axis substantially parallel to the long axes of the first and second reflector means, being mounted above said first and second reflector means and away from the path

through which the illuminated linear region can be viewed from above through said illumination apparatus;

beamsplitter means mounted in the path through which the illuminated linear region can be viewed from above through said illumination apparatus, tilted to the optical viewing axis, and being positioned to reflect the focussed beam from the fifth reflector means to the illuminated linear region; and

third linear light source means mounted parallel to said fifth reflector means to direct light onto substantially the entire surface of the fifth reflector means with said third linear light source at a first focus of the fifth reflector means and the illuminated linear region at the second focus of the fifth reflector means with the beam from the fifth reflector means being reflected by the beamsplitter means.

30. An illumination device for an optical scanner for illuminating a line on the surface of a workpiece, said device comprising:

at least one elongated light source extending in a direction substantially parallel to the line, and emitting a solid angle of light; and

at least one light concentrator having a surface defining a segment of a cylinder disposed with respect to said source such that said source is imaged onto said line, whereby said line is illuminated by at least one solid angle of uniform illumination from said source.

31. The device of claim 30, further comprising a second elongated light source extending in a direction substantially parallel to the line, and emitting a second solid angle of light; and

a second reflective light concentrator having a surface defining a segment of a cylinder disposed with respect to said source such that said second source is imaged onto said line, whereby said line is illuminated by two solid angles of uniform illumination from said sources.

32. The device of claim 31, wherein said first and second solid angles of illumination are spaced from one another, and said illumination device further comprises:

a third elongated light source extending in a direction substantially parallel to the line, and emitting a solid angle of light;

a beam combiner; and

a third reflective light concentrator having a surface defining a segment of a cylinder disposed with respect to said third source and said beam combiner such that said third source is imaged onto said line, and such that a third solid angle of uniform illumination from said third source fills the space between the solid angles of illumination from said first and second concentrators, and wherein the levels of illumination provided by said first, second and third light concentrators are substantially uniform.

33. The device of claim 32, further comprising planar reflective members disposed at either end of said concentrator and substantially perpendicular thereto.

34. The device of claim 30, wherein said at least one elongated light source comprises a bundle of optical fiber, and a lamp disposed near one end of said bundle, the other end of said bundle being spread along a line to define said elongated light source.

35. The device of claim 30, wherein said at least one cylinder is an elliptical cylinder.

36. The device according to Claim 34, wherein there are:

first and second elongated light sources extending in a direction substantially parallel to the line, and emitting solid angles of light; and

first and second light concentrators having surfaces defining segments of cylinders, said concentrators being disposed with respect to the corresponding sources such that said sources are imaged onto said line, and whereby said line is illuminated by two solid angles of uniform illumination from said sources.

37. The device of claim 36, wherein said first and solid angles of illumination are spaced from one another, said device further comprises:

a third elongated light source extending in a direction substantially parallel to the line, and emitting a solid angle of light;

a beam combiner; and

a third light concentrator having a surface defining a segment of cylinder disposed with respect to said third source and said beam combiner such that said third source is imaged onto said line, whereby a third solid angle of uniform illumination from said third source fills the space between the solid angles of illumination from said first and second concentrators, and wherein the level of illumination provided by the third source is substantially uniform with respect to the level of illumination provided by the first and second sources.

38. The device of claim 36, wherein said first and second beam concentrators are reflective.

39. The device of claim 36, further comprising planar reflective members disposed at either end of said concentrators and substantially perpendicular thereto.

40. The device of claim 36, wherein at least one of said light sources comprises a bundle of optical fibers, and a lamp disposed near one end of said bundle, the other end of said

ndle being spread along a line to define said at least one elongated light source.

41. The device of claim 36, wherein at least one of said cylinders is an elliptical cylinder.

42. The device of claim 36, wherein said first and second light concentrators comprise refractive elements.

43. The device of claim 36, wherein said first and second solid angles of illumination are spaced from one another, and said device further comprises:

a third elongated light source extending in a direction substantially parallel to the line, and emitting a solid angle of light;

a beam combiner; and

a third light concentrator having a surface defining a segment of a cylinder disposed with respect to said third source and said beam combiner such that said third source is imaged onto said line, whereby a third solid angle of uniform illumination from said third source fills the space between the solid angles of illumination from said first and second concentrators, and wherein the radiance of the third source may differ from the radiance of the first and second sources.

44. The device of claim 36, further comprising first and second aberration plate means disposed between the first and second sources and the respective concentrators, to broaden the useful illumination volume.

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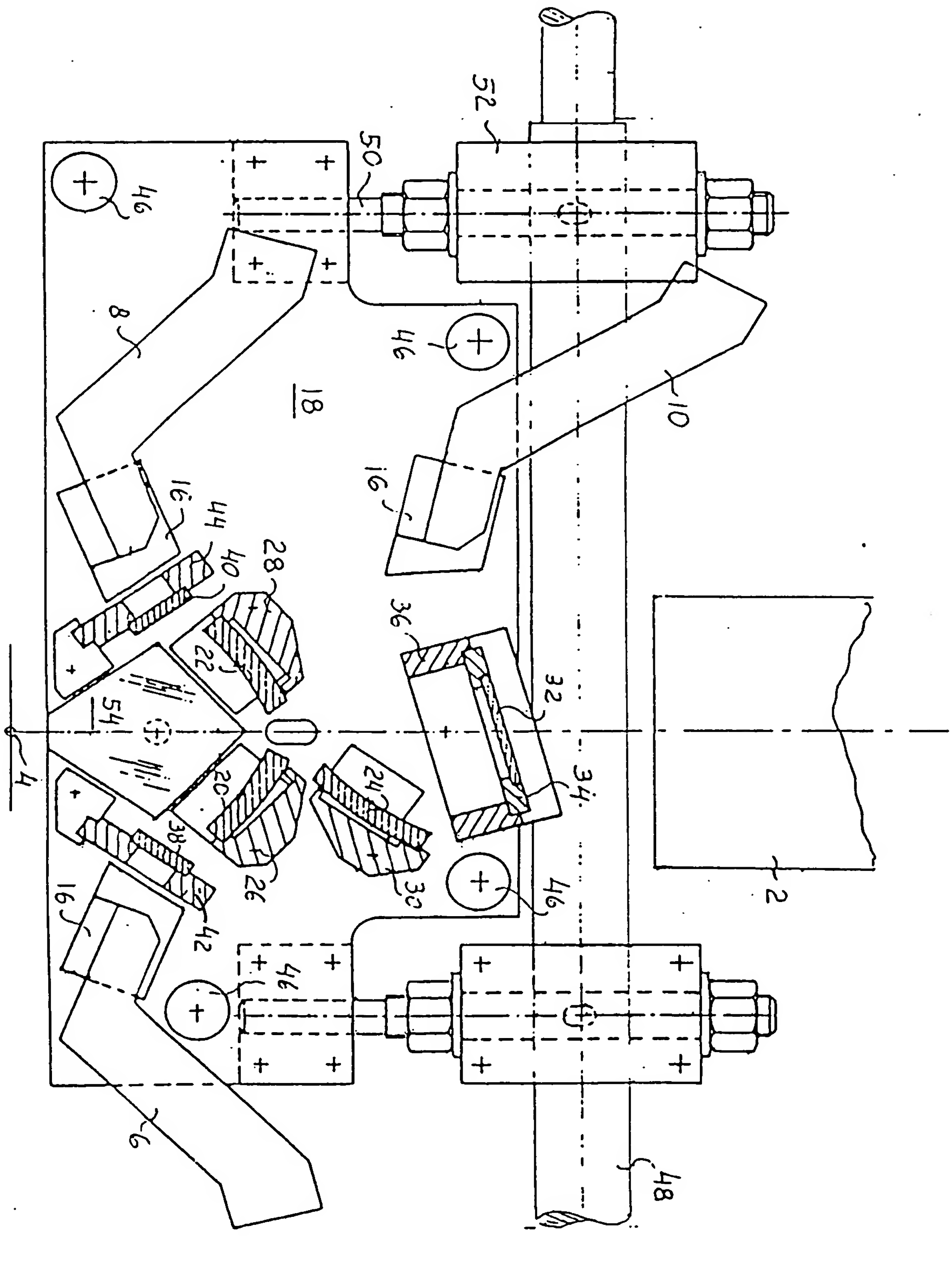

Fig. 1

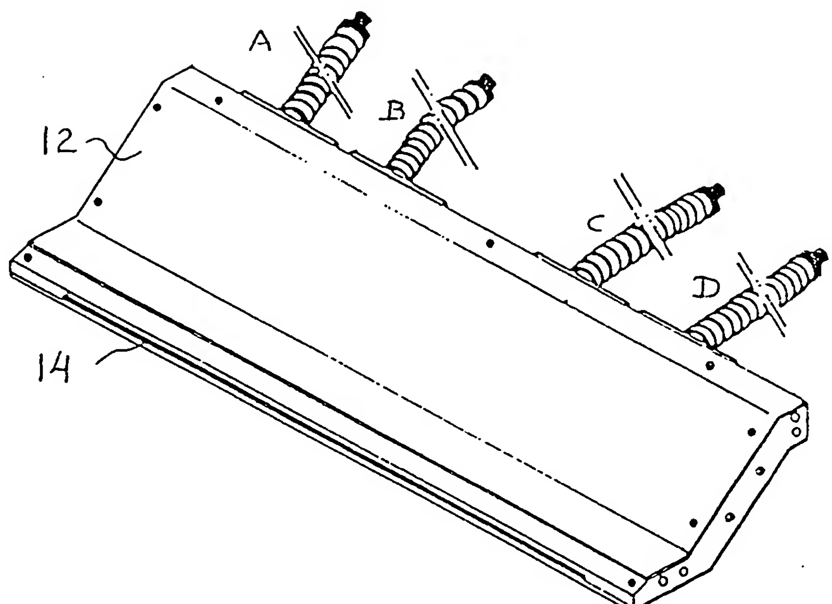

Fig. 2

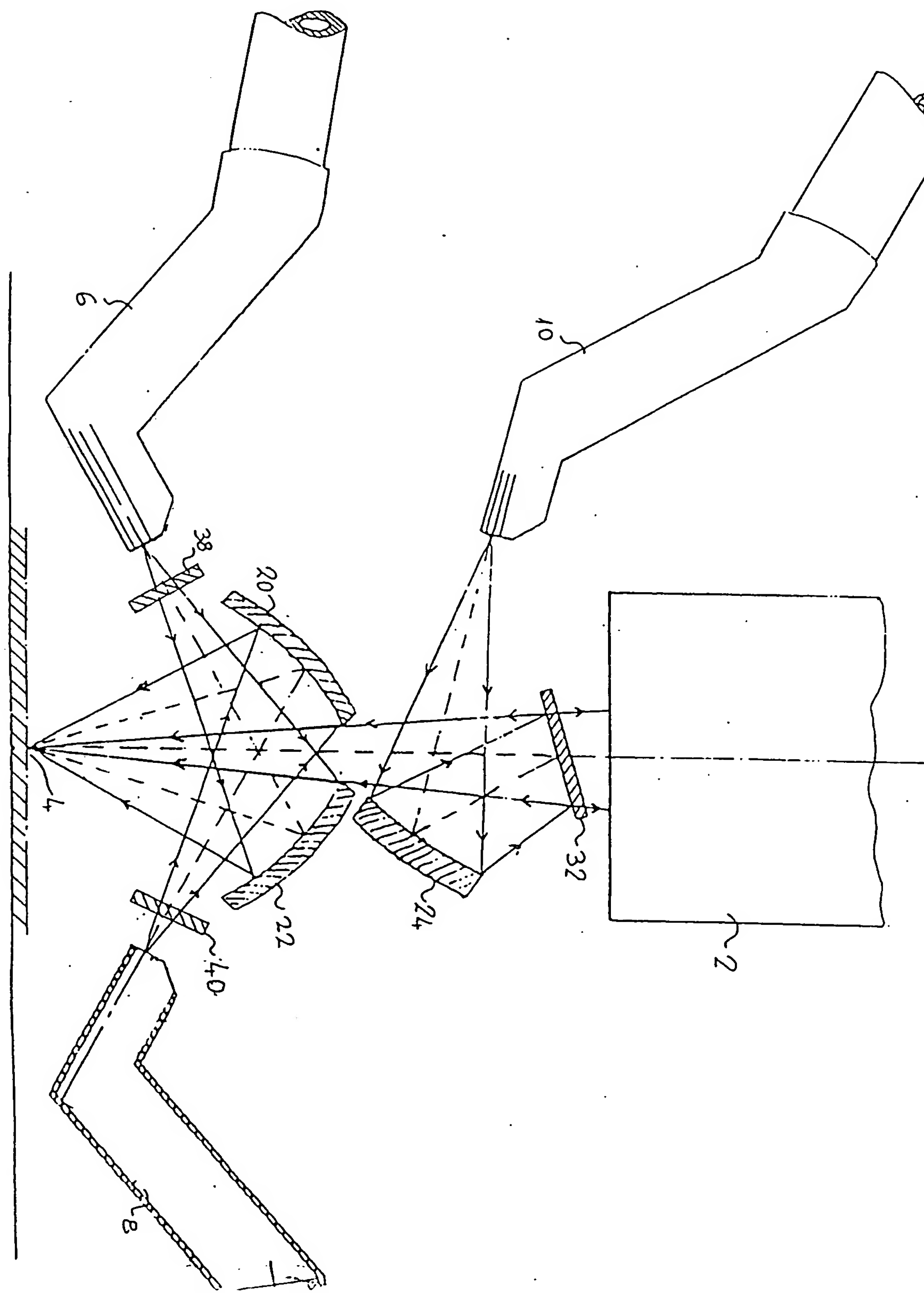

Fig. - 3